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DO INVISIBLE BUBBLES EXIST IN THE SEA?

by

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Introduction

The existence of bubbles in the upper layers of the sea is of interest to both marine biologists and acoustic physicists. Visible bubbles are caused principally by the entrainment of air from breaking waves. Other causes are sea-floor gas seepage, fish burps, and decomposition of bottom detritus.

These visible bubbles are all transient in nature. There is a possibility that longer-lived, very fine, invisible, bubbles exist beneath the sea surface.

One reason to believe that such invisible bubbles may exist is that foam tends to accumulate on the sea surface on quiet days, especially in sea surface slicks. This foam may have been caused by very fine bubbles which though temporarily retarded from surfacing by organic matter in the water or by the downward convergence circulation found under some types of sea surface slicks, have reached the surface by some of the processes to be discussed.

Various factors related to the possible formation and behavior of invisible bubbles in the sea have been investigated, with particular reference to the oceanographic conditions encountered under slicks.

Foam in Slicks

Foam is normally associated with breaking waves forming white caps when the wind is greater than 6 m/sec. The duration of foam thus produced was noted to depend on the size of breaking wave and the organic content of the water. For example, in low latitudes off the Indian coast under conditions of Wind Force 4, foam produced by white caps was observed to last for only 3 seconds in one season, when the water was clear. Under similar wind conditions, it lasted as long as 20 seconds during the upwelling season when the water was colder and full of plankton. The foaming of sea water has also been studied by Abe[1] who found by shaking filtered sea water collected off Japan that the half-life of foam produced was about 5 seconds at 20°C.

In some slicks foam has been observed in the open sea in the absence of white caps (Figures 1, 2). Sometimes it is a broad band which becomes concentrated into a line with increasing wind. Other patches appear to be related to a zone of surface convergence. It is not known whether this foam is the result of a previous strong wind or whether it is produced in the water column.

Temperature in Slicks

The thermal structure of the water associated with slicks was

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FIGURE 1. LINE OF FOAM AT SURFACE ON A SLICK (OFF GUAYMAS IN THE GULF OF CALIFORNIA, MEXICO).

FIGURE 2. PATCH OF FOAM AT SURFACE (OFF MISSION BEACH, SAN DIEGO, CALIFORNIA).

investigated. With BTs and towed thermistors it was found that the surface temperature of the water in slicks is higher than the water between them when a series of slicks occurs. Assuming that higher temperatures are found at the immediate surface in spring and summer,[2] this finding would indicate that the immediate surface waters were moving toward and concentrating in the slick band. Another factor which contributes to the heating of slicks, as will be pointed out later, is the greater absorption of solar radiation.

The vertical and horizontal temperature structures normal to slicks showed that the isotherms were depressed under nearly all of the slicks (Figures 3, 4). The isotherms are as much as 30' lower under these slicks than in adjacent water. To maintain this unstable density field a downward force is necessary. If the water is moving downward small bubbles might be carried with it.

Transparency in Slicks

The transparency of slicks was also examined by towing a hydro-photometer at a constant depth through a series of slicks. Unusually high-turbidity zones were encountered at a depth of 6 feet under the slicks. (Figure 5). In the relatively clear water between slicks about 60 to 70 per cent of the light was transmitted through a meter path, whereas under the slicks only 10 to 40 per cent was transmitted. These turbidity zones are the result of either the surface convergence in the slicks, or an internal wave bringing up turbid material from the subsurface turbid layers. The
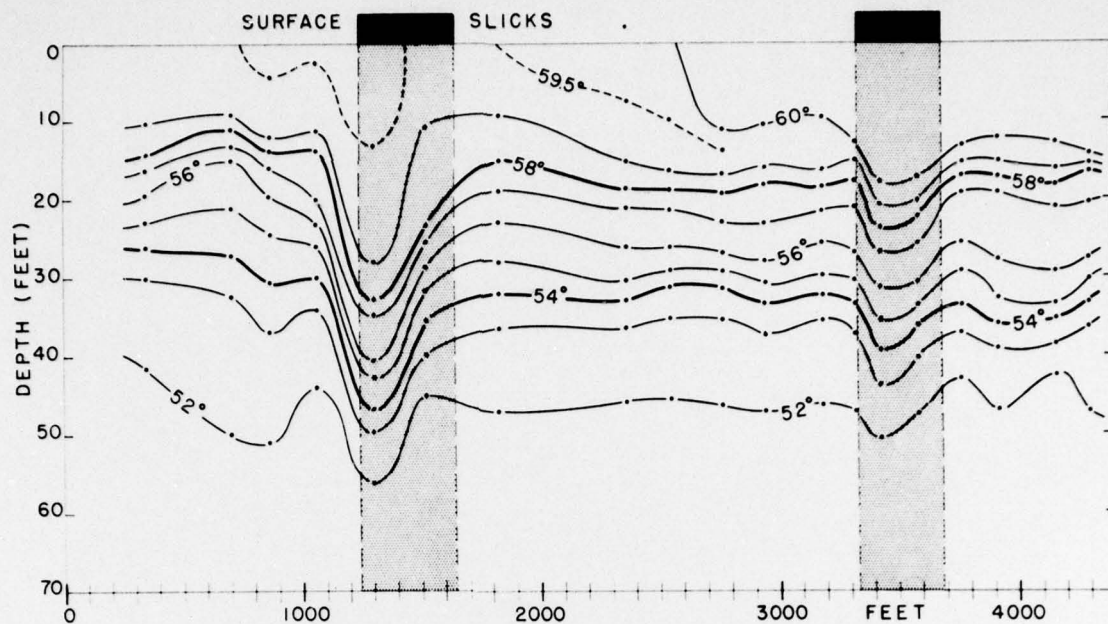
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FIGURE 3. VERTICAL TEMPERATURE STRUCTURE UNDER TWO ADJACENT SLICKS (°F).

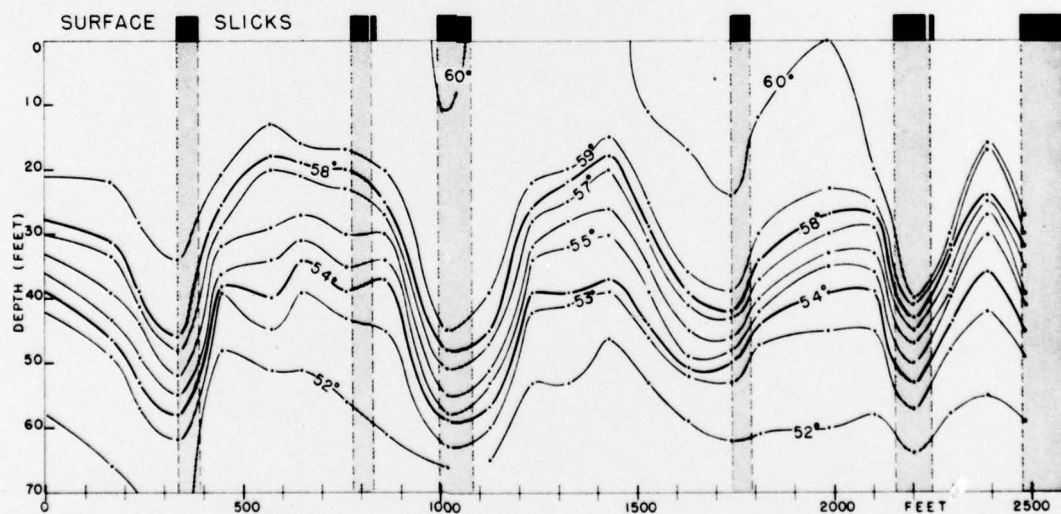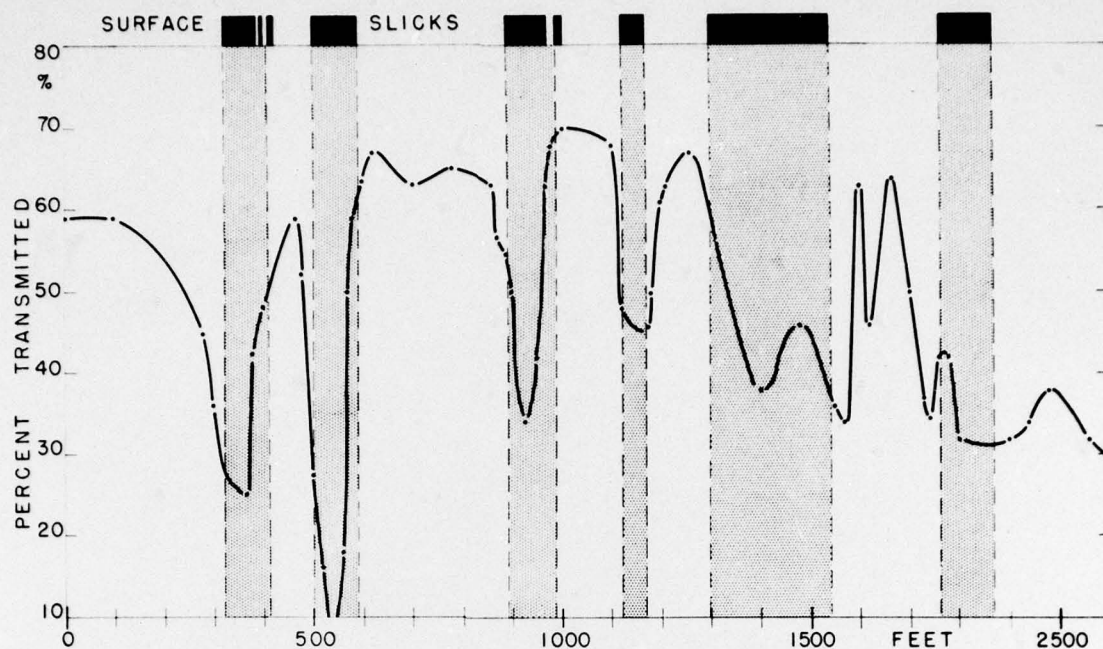**FIGURE 4.** VERTICAL TEMPERATURE STRUCTURE UNDER A SERIES OF SIX SLICKS. (°F).

FIGURE 5. TRANSPARENCY AT SIX FEET UNDER A SERIES OF SIX SLICKS.
(TRANSPARENCY IN PER CENT OF LIGHT TRANSMITTED REFERRED TO PURE
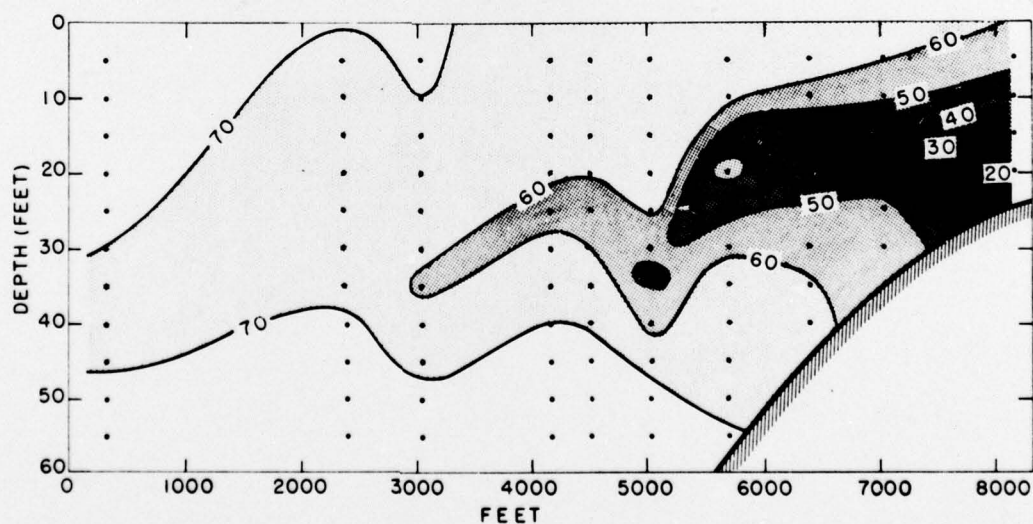DISTILLED WATER AS 100 PER CENT).

FIGURE 6. TRANSPARENCY SECTION EXTENDING OUT FROM SHORE.
(TRANSPARENCY IN PER CENT OF LIGHT NOT ATTENUATED OVER A METER PATH
REFERRED TO PURE DISTILLED WATER).

depression of the thermocline tends to favor the former method of concentrating turbid material under slicks.

In south California, where most of these measurements were made, the material causing the turbidity zones near the surface was found to be mainly organic. Some turbid water caused by plankton develops in situ. Other turbid water appears to originate from the shallow near-shore region (Figure 6). Net hauls and diver-collected samples of the material causing a shallow turbid layer were analyzed and found to be phyto-and zoo-plankton alive and in varying stages of decomposition. From the variety of organisms and environment it is to be expected that the composition of the turbid layer will vary both with the season and with the physical and chemical properties of the water which are conducive to plankton production.

Other sources of bubbles

The possibility of bubbles being produced in situ cannot be overlooked. Experiments in the laboratory and at sea indicate that divers can visually distinguish individual bubbles as small as 0.06 mm in diameter. Large clouds of bubbles produce murkiness in water. Frequently a Tyndall effect is apparent in shallow water looking through the water at right angles to ripple-induced rays of bright sunlight. This effect greatly accentuates the ability of divers to distinguish small objects, such as fine bubbles in the water. However, under normal conditions no bubbles have been observed that persist in the water column. All visual bubbles rose towards the surface, increasing in size on reduction in pressure and bursting at the surface.

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If bubbles smaller than 0.06 mm exist in the water column, some factor must keep these minute bubbles from going into solution. Liebermann[3] has shown that bubbles of small size cannot be made to persist for any periods of time that are comparable to the periods that sound attenuation has been observed. In his laboratory experiments, small bubbles quickly went into solution. He concludes that the effect of bubbles larger than one micron on acoustical experiments in water can be expected to be negligible, unless bubble generation occurs. The same conclusion undoubtedly holds in the ocean.

Liebermann also showed that organic stabilizers do not significantly inhibit bubble solution. From the lack of visual detection of bubbles, together with the evidence that small bubbles rapidly go into solution, it appears that if bubbles are present in the sea they must be generated somewhere in the water column and must exist in a relatively transient state. According to Miyake[4] bubble formation may occur in situ by an increase in temperature or salinity when the water is saturated with air. He also mentioned that vertical currents and biological action are capable of producing bubbles.

Another approach to the problem of bubble generation is through the study of the oxygen saturation of the water. Oxygen concentration at various depths and its relation to temperature structure and the turbid layer were investigated off Mission Beach, near San Diego, California. On several occasions the turbidity structure of the water showed a layer of

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low transparency at depths from about 12 to 25 feet, which at that time corresponded to the lower part of the thermocline.

The oxygen content of the water in the spring and summer was found to be maximum below the surface and above the densest turbid layer in all cases (Figure 7). However, when the per cent saturation was determined for in situ conditions, that is, when the solubility was corrected for pressure, temperature and salinity, the vertical saturation curves differed from the oxygen content curves (Figure 8). The in situ calculations, assuming nitrogen saturation at all levels, showed that the upper 12 to 14 feet were supersaturated with oxygen. The maximum supersaturation which occurred at the surface ranged from 120 to 148%. This high oxygen, undoubtedly derived from photosynthesis of plant organisms comprising a high percentage of the turbid layer, occurred on the upper side of the layer. Thus, the increased light at the upper side of the layer caused a higher rate of photosynthesis, and therefore a greater oxygen saturation at this level.

Unusually high oxygen content is not surprising under conditions of high phytoplankton production. For example, Nusbaum,[5] when determining the oxygen content of the waters near San Diego during periods of high plankton blooms, reports that the water was observed to have an oxygen saturation as high as 200 per cent. Pickard[6] reports that oxygen in the waters of the British Columbia inlets may be supersaturated as high as 170 per cent due to the action of large concentrations of phytoplankton. The supersaturation of water samples can be reduced by shaking the sample,
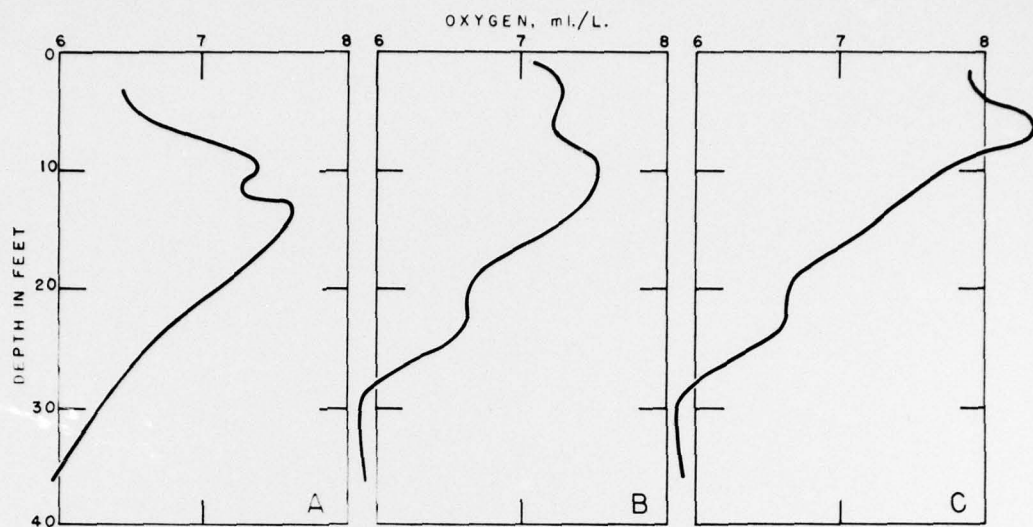
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FIGURE 7. VERTICAL DISTRIBUTION OF TOTAL DISSOLVED OXYGEN AT THREE STATIONS OFF MISSION BEACH.
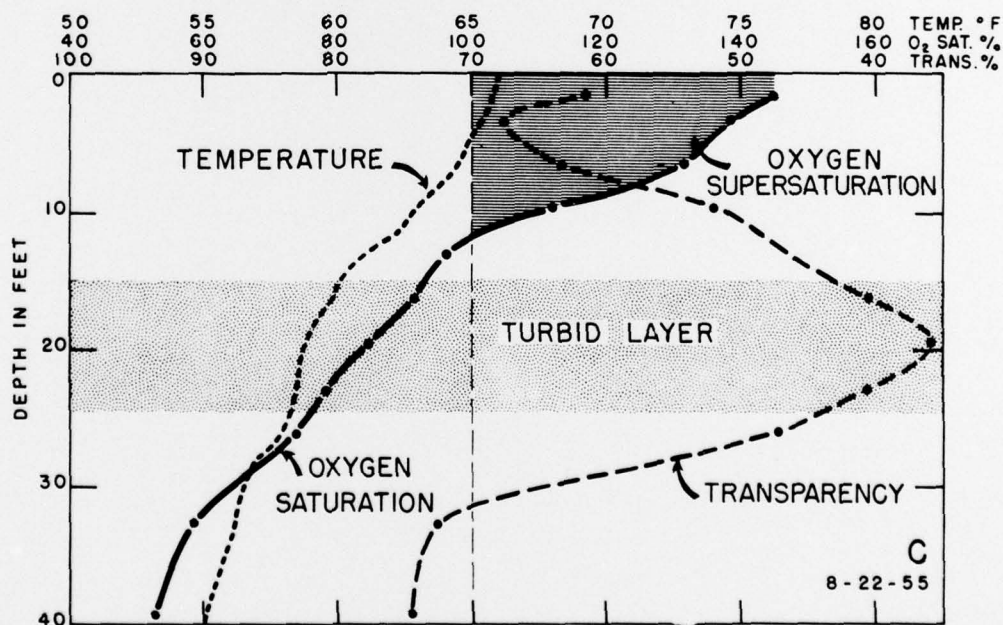

FIGURE 8. RELATION OF VERTICAL TEMPERATURE, TRANSPARENCY AND OXYGEN SATURATION OFF MISSION BEACH.

indicating the instability of the oxygen in the water.

Under conditions of supersaturation, a small bubble introduced either by organisms in the water column or from the surface will not diminish in size but will actually grow. However, these bubbles will tend to rise at increasing speed and be lost at the surface. Thus, persistence of these bubbles over long periods of time cannot be expected, unless some mechanism exists for keeping them submerged or unless there is a continual source at depth. The circulation causing the down-bowing of the isotherms in the near vicinity of slicks could be just such a mechanism if the bubbles were extremely small. In addition, the particles responsible for the high turbidity of the water under slicks could easily attach themselves to extremely fine bubbles and prevent them rising to the surface.

It has also been noted that foam lines are more prevalent after storms. This might at first be attributed to the increased entrapment of air by breaking waves. But foam thus produced has been demonstrated to have a short life, the foam lines, therefore, must be due to gases released from the supersaturated layer by the increased turbulence produced by the higher wave motion continuing after the storm.

As pointed out earlier, a thick layer of surface water is found under slicks because of convergent circulation. The surface water has the highest oxygen saturation. If further heating takes place in the slick zone the saturation will increase and may reach a point where some of the gas will come out of solution in the form of bubbles. In such turbid areas the

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radiation is absorbed at a lesser depth because of the particles in the water, resulting in a higher surface temperature than in adjacent clearer areas where the heating is distributed over greater depths. This heating may be also enhanced by the "green house" effect of the glassy contaminate layer comprising the surface of slicks. The surface water temperature in slicks was observed to be higher than the temperature between slicks by an average of 0.3°F in April and 2.0°F in August, with a maximum of 2.8°F. (Figure 9). Under a heating of 2°F the saturation of all gases will increase and some of the gas will be forced out of solution in slicks. Because of the high organic concentration, the bubbles thus formed persist at the surface as foam. In some slicks during quiet weather, bubbles have been seen to suddenly emerge from the water, temporarily remain at the surface, and then burst. Others persist as foam. These apparently are derived from the heating of gas saturated water.

Still another mechanism by which oxygen bubbles may be produced is brought about by the action of internal waves. If supersaturated or nearly supersaturated water is brought up from one depth to a lesser depth the per cent saturation increases (Figure 10). This vertical displacement may amount to at least 30 feet as demonstrated by the height of the observed internal waves (Figure 4). Similar changes in pressure on oxygen-saturated sea water caused it to release bubbles in laboratory experiments which were performed in a pressure chamber by bubbling oxygen through water, releasing the pressure, and noting the formation
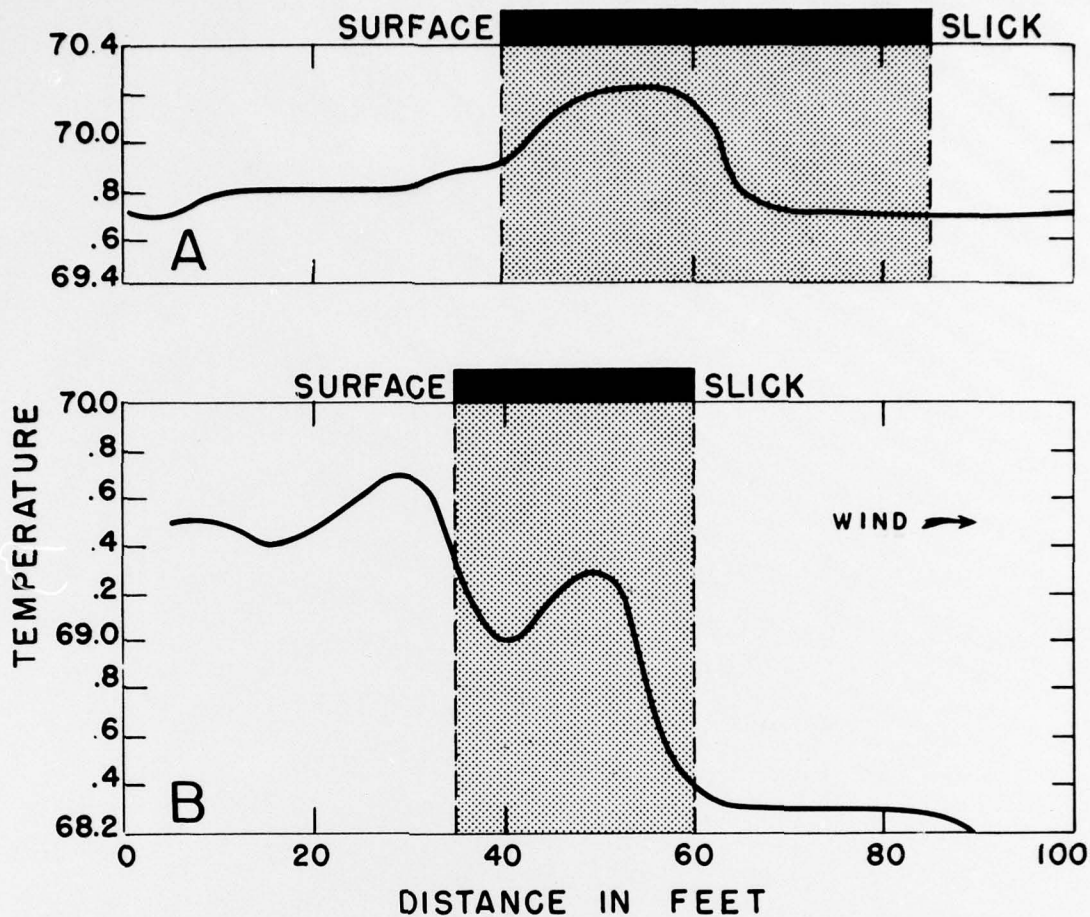
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FIGURE 9. SURFACE TEMPERATURES THROUGH FOAM SLICKS IN AUGUST.
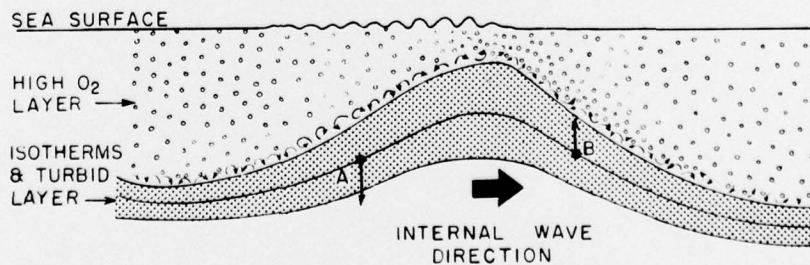A. CONVERGENCE TYPE SLICK.   B. BOUNDARY TYPE SLICK.

FIGURE 10. SCHEMATIC REPRESENTATION OF INTERNAL WAVE, TURBID
LAYER AND OXYGEN DISTRIBUTION.

of bubbles.

In addition to the reduced pressure on the crest of internal waves there is usually some turbulence associated with the thermocline as indicated by the visual distortion of objects when viewed through it, and the distortion of dye marker when dropped through the water. It is believed possible that this turbulence and the reduced pressure caused by dominant internal waves is of sufficient influence on supersaturated water to free some of the oxygen and other gases in the form of small bubbles in the sea, which may cling to organic matter and be concentrated in slicks. Or the bubbles may continue to grow until they reached the surface and sometimes accumulate as foam.

Observations

An attempt was made to collect gas bubbles which might periodically be rising in the water column. This was done by suspending a 30-inch diameter funnel upside down from a buoy at 9 feet below the surface (Figure 11). An inverted bottle of water was placed over the small end of the funnel. Thus, any gas rising in the water column under the funnel would be trapped in the bottle.

Considerable difficulty was experienced in keeping the funnel secured to the buoy because of the difference in vertical drag of the two. However, a small amount of gas was collected and found to be oxygen, carbon dioxide, and hydrocarbons. Another difficulty with this approach is that organic matter also collects in the funnel, and when left for several days in the
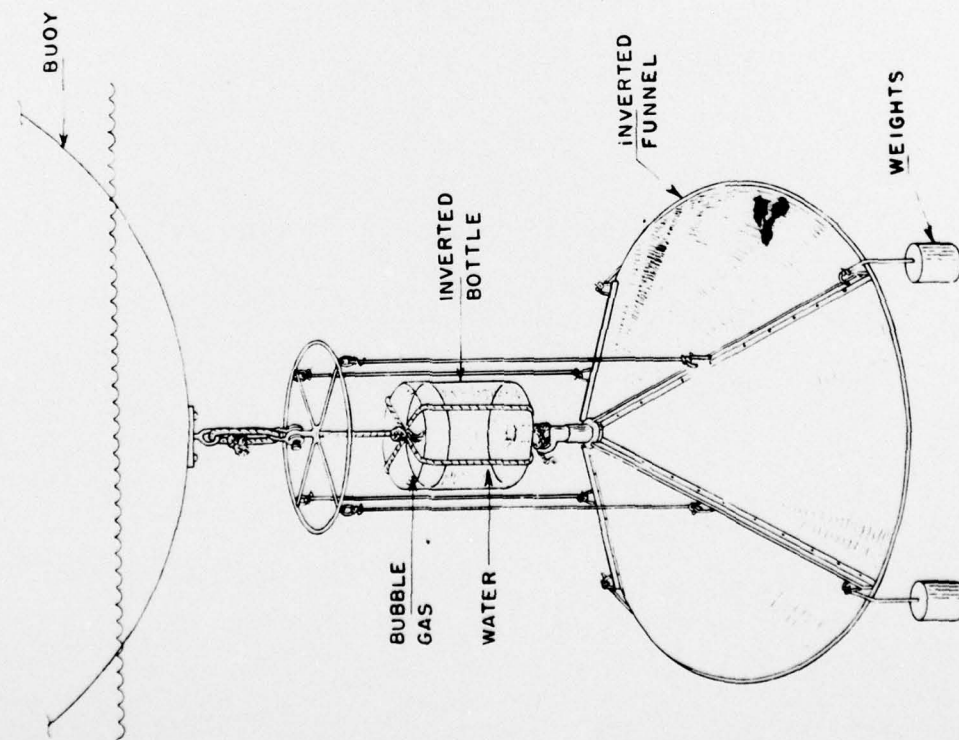
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FIGURE 12. SKETCH OF APPARATUS FOR COLLECTING
GAS IN FOAM.

FIGURE II. SKETCH OF FUNNEL USED TO COLLECT
GAS RISING IN THE WATER COLUMN.

water, decomposes using up the oxygen. Thus the oxygen content was less than in air.

A similar funnel arrangement was set up at Sweetwater Lake, a fresh water lake near San Diego, California. Here gas collected more rapidly. Actual bubbles or groups of bubbles can be observed to rise from the lake bed by means of an echo sounder. The gas was analyzed and found to contain no oxygen but carbon dioxide, methane, and hydrogen sulfide. This gas resulting from decomposition of bottom detritus by bacterial action will be collected by the funnel even though the upper levels are supersaturated with oxygen. Such bubbles are less likely but possible in shallow shelf regions since the bottom water normally contains a considerable oxygen content. Under accumulations of detritus on the bottom, such as dead kelp, the oxygen content is reduced.

Another approach was to study the nature of foam and gases produced in situ. A foam-collecting apparatus was devised (Figure 12). It consists of two bottles arranged to float one above the other in a frame. Initially the upper bottle is filled with water and allowed to syphon through a hose to the lower bottle. The syphoning only takes place when gas is introduced through a collecting hose also connected to the upper bottle. The other end of the collecting hose opening is attached in the apex of a V-shaped float. When sufficient foam is herded into the float a ball valve is opened in the base and the foam is sucked into the upper collecting bottle. An aspirator bulb attached to the lower bottle enhances the syphoning action.

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Gas thus obtained by swimmers using the apparatus in the open sea was analyzed for oxygen, hydrogen, carbon dioxide, etc. It was found to contain as much as 28. 8% oxygen and small amounts of carbon dioxide. The remainder was assumed to be nitrogen. In other words, this sample of foam could not be derived from the simple entrapment of air or the decomposition of organic matter. It must be due to the release of oxygen from the water.

Conclusions

In answering the question, "Do invisible bubbles exist in the sea?" it can be concluded that some bubbles from gas seeps, decomposition of bottom detritus, and breaking waves have definitely been observed. Oxygen bubbles produced by phytoplankton on the other hand can only be inferred because of their extremely small size and their probable periodic nature of forming. Phytoplankton do produce oxygen and the water can become supersaturated with this oxygen as well as air. Mechanisms are present in sea which are capable of releasing this oxygen and other dissolved gases as bubbles by the action of turbulence, temperature increase, and pressure decrease. This release of gases is further substantiated by the accumulation of foam on slicks in the absence of wind. It seems likely therefore that invisible bubbles can be produced and therefore do occasionally exist in the sea, especially in the convergent circulation under slicks.

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